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Current State of Pineries in Zhytomyr Polissia Under the Influence of Environmental Factors

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Abstract. Recently, there has been a massive drying of conifers all over the world. In North America and Siberia, there are millions of hectares of shrunken plantings; in Europe, pines and firs have been drying up over the past two decades. Furthermore, considerable damage is caused to woody plants by phyto-pest and phyto-diseases, since mass reproduction of *Ips typographus* Linnaeus, *Ips acuminatus* Gyllenhal has been observed in Europe in recent years, *Dendroctonus micans* Kud – in North America, *Polygraphus proximus* Blandford – in East Asia. Nematodes also cause significant damage to pine forests. Among phyto-diseases, *Heterobasidion annosum* (Fr.) Bref. harmfully affects *Pinus sylvestris* L. The appearance of foci of shrunken trees in different parts of the globe indicates the global nature of processes associated with cyclical planetary processes and climate change. This study describes climate changes in the research region for 1961-2020. According to the analysis, it was found that for 2009-2020, considerable damage to pine plantations in Zhytomyr Polissia is caused among needle-eating insects — *Panolis flammea* Denis & Schiffermuller, *Diprion pini* L., *Neodiprion sertifer* Geoffroy; among other pests – *Aradus cinnamomeus* Panz, *Dendrolimus pini* L., *Bupalus piniarius* L. The greatest harmful effect that pineries have recently sustained has been caused by *Diprion pini* L. It was also found out that among phyto-diseases suffered by the pine forests, significant damage has been done by *Heterobasidion annosum* (Fr.) Bref., with the damaged area of 13.0-14.2 thousand hectares. Hydrothermal analysis was performed for 2009-2020. The influence of solar activity on the number of phyto-pest and diseases is analysed. This paper provides the estimate of the amount of CO_2 emissions is given for 2009-2020. It was found that since 2014, the amount of carbon dioxide emissions has decreased from 1.5 million tonnes to 0.6 million tonnes. Correlation analysis of all indicators indicated a high mutual influence between the area of trees damaged by insect pest, root sponge, the Wolf number, and CO_2 emissions to the environment. Mathematical dependences are obtained to predict the influence of the W number on damage to pineries by forest pests and diseases in the conditions of Zhytomyr Polissia

Keywords: climate change, Phyto-pests and diseases, CO_2 emissions, solar activity, hydrothermal coefficient, correlation, mathematical modelling

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INTRODUCTION

Climate changes in Ukraine are more intense than global changes in the world. According to scientific research of the Institute of Irrigated Agriculture of the National Academy of Agrarian Sciences (NAAS) [1], the Institute of Plant Protection of the NAAS [2] and the Institute of Agroecology and Nature Management of the NAAS [3] in Ukraine for 1973-2016, the average annual air temperature increased by 2°C, an increase in precipitation, which had the nature of heavy rains, as well as an increase in the wind regime. Such changes adversely affect both agricultural crops and woody plants. According to literature sources, mass drying of coniferous woody plants is observed in forest biocenoses. The causes of death of pineries include increased anthropogenic impact on the environment, climate changes, namely an increase in air temperature, a decrease in precipitation [4-6]. Apart from the weakening of woody plants, there is an increase in foci of insect pests [7-9] and phyto-diseases [10-12].

Forest conservation is an important task because in comparison with other natural ecosystems, forest ecosystems are of great climate-stabilising importance and constitute a natural framework for natural landscapes and preserve forest biodiversity under their tent. Even though among the main forest-forming species in Ukraine, Scots pine is the predominant tree species and occupies 33% of the land area of the Forest Fund of Ukraine, pine forests require conservation. Diverse scientific research to identify the causes of forest death will contribute to solving the issues of their restoration and multiplication [13; 14].

Since 2010, Ukraine has seen a massive withering of numerous main forest-forming tree species – Pine (*Pinus*), Oak (*Quercus*), spruce (*Picea*), Birch (*Betula*) and ash (*Fraxinus*). A similar situation is observed on all continents in the forest biocoenoses of the temperate zone of the Northern Hemisphere [7-9]. The situation is particularly catastrophic in coniferous forests. Thus, the withering of coniferous species in North America and Siberia totals millions of hectares. The situation is no better in Europe, where over the past two decades there has been a massive withering of Scots pine (*Pinus sylvestris* L.) and European spruce (*Picea abies* (L.) H. Karst). Withering of the main forest-forming tree species in the forests of the Northern Hemisphere in most cases have similar signs of the process and are caused by outbreaks of mass reproduction, similar in biology to stem pests. For example, North America has recently witnessed a massive reproduction of dendrocton (*Dendroctonus micans* Kud), East Asia – the Ussuri polygraph (*Polygraphus proximus* Blandford), a spruce bark beetle in Europe (*Ips typographus* Linnaeus) and sharp-dentated bark beetle (*Ips acuminatus* Gyllenhal) [15-17]. Nematodes also cause significant damage to pine forests [14]. Among phyto-diseases, harmful effect is caused by a fungus from the class of Basidiomycetes – *Heterobasidion annosum* (Fr.) Bref. to the Scots Pine (*Pinus sylvestris* L.) [10-12]. The simultaneous emergence of foci of shrunken tree species in many countries and an increase in their area indicates the global nature of the processes. It is most probable that this is connected with cyclical planetary processes enhanced by anthropogenic impact and expressed in an increase in air temperature and a decrease in precipitation in recent decades in most of the globe [6; 18; 19].

The purpose of this study is to analyse the influence of environmental (air temperature, humidity, precipitation, CO_2 emissions, hydrothermal regime) and planetary (solar activity) factors on the occurrence of foci of insect pests and phyto-diseases in the Zhytomyr Polissia zone.

LITERATURE REVIEW

Various climate changes that occur in the world are planetary in nature. In his study Earth Echo of Solar Storms, which was published in 1976, Professor A.L. Chizhevsky drew attention to the fact that there is a certain correlation between the activity of the sun and the periods of outbreaks of pandemics, epidemics, epiphytic epizootics on Earth [20]. Italian-born microbiologist P. Faraone (1995) drew attention to the pattern of growth of bacterial colonies during years of minimal solar activity [21]. Later, Ukrainian researchers V.S. Martynyuk, N.A. Temuryants, B.M. Vladimirsky [22] in their monograph Nature Does Not Have Bad Weather: Space Weather in Our Lives addressed the change in biological, social, and technological processes impacted by solar activity. In their scientific study The Influence of Solar Activity on the Temperature of the Troposphere and Ocean Surface H.O. Zherebtsov, V.A. Kovalenko, S.I. Molodykh, K.E. Kirichenko [23] noted that the ambient temperature affects the concentration of CO_2 and geomagnetic activity. P.P. Melnyk [24] in his monograph Ecological and Economic Foundations of Nature Management in Agroecosystems pointed out that wheat yield depends on the number of sunspots. In his scientific paper, V.B. Chernyshev drew attention to the fact that the activity of the sun affects the vital activity of insects [25]. Scientific publications of foreign authors note that the activity of the sun has a direct impact on forest fires in Southern Europe [26]. More detailed information about this correlation was published in their papers by researchers M.M. Radovanović, T.A.M. Pavlović et al. [26].

When conducting statistical analysis, scientists V.V. Lavniy and V.H. Mazepa [27] found a direct correlation between such indicators as solar activity and annual winds. In their research, I. Dorotovič, J. Louzada, J. Rodrigues, V. Karlovský analysed the effect of solar activity on pine growth [28].

To date, over fifty forecasts of the 24th cycle of solar activity have been published, which indicate the value of the maximum Wolf number from 42 to 190 [29-31]. The change in the hydrological regime is directly related to the average annual air temperature, which has recently increased in Ukraine by 2°C. Lately, the level of subsurface water and the water level in reservoirs has considerably decreased. One of the causes of climate

change is human activity, since 67% of greenhouse gases are released into the environment through the burning of fossil fuels and energy. To assess changes in the hydrological regime, the Selyaninov hydrothermal coefficient (HTC) is applied [19]. The hydrothermal humidification coefficient allows identifying the humidity of the territory and is determined by the amount of precipitation for the period when the average daily air temperature was above 10°C, which is the period of active vegetation of plants. After all, moisture availability has a direct impact on the sanitary condition of forest stands [5; 19; 32].

Apart from anthropogenic human activity, natural factors, such as volcanic eruptions, also have an adverse environmental impact, and 3-4 gigatonnes per year are released into the environment under their influence. In natural conditions, carbon dioxide constitutes a limiting factor in photosynthesis and not all plants can withstand high concentrations of CO_2 (ten times or more). Increased CO_2 concentration in the environment slows down the growth and development of the plant and a state of suspended animation occurs. More sensitive plants are damaged by phyto-diseases. Furthermore, according to scientists P.G. Guerenstein, and J.G. Hildebrand [33], V.P. Akatov [34], A. Fangmeier [35], R.M. Srinivasa [36], an increase in the concentration of carbon dioxide promotes the reproduction of insect pests [37; 38].

MATERIALS AND METHODS

To achieve the purpose of this study, the necessary statistical information was collected, which included the data from the Main Statistics Department of the Zhytomyrska Oblast, indicators of Ukrainian hydrometeorological centre and the State Agency for Forest Resources of Ukraine (Form No. 12-F), as well as the materials provided by the S.I. Subbotin Institute of geophysics of the National Academy of Sciences of Ukraine (NAS of Ukraine).

According to the obtained data of the Ukrainian hydrometeorological centre, the study analysed the dynamics of climate change for 1961-2020, namely the average annual air temperature, average annual relative humidity, and average annual precipitation.

According to the provided statistical indicators of the State Agency for Forest Resources of Ukraine, the author of this paper analysed the dynamics of the occurrence of insect pests and Heterobasidion annosum in pineries of Zhytomyr Polissia for 2009-2020. The years of increase in forest areas covered with forest vegetation damaged by harmful entomofauna and phyto-diseases were determined.

According to the materials provided by the S.I. Subotin Institute of Geophysics of the NAS of Ukraine, the study established periods of growth and decline of solar activity (W number) for 2009-2020.

To establish the quantitative indicator of aridity of the studied area, the formula of H.T. Selyaninov was used [11]:

$$HTC = \frac{\sum \mathrm{P}}{0.1 \times \sum t_{rel>10}} \quad (1)$$

where $\sum$ P is the sum of precipitation for the month, in mm; $\sum$ t is the sum of the average daily temperature above 10°C.

According to Eq. (1), if HTC<0.4 is a very severe drought, HTC 0.4-0.5 is a severe drought, HTC 0.6-0.7 is an average drought, HTC 0.8-0.9 is a weak drought, HTC 1.0-1.5 is sufficiently humid, HTC 1.5 is excessively humid.

The author of this paper established the years of drought and humidity in the region under study for 2009-2020, and the calculated the amount of greenhouse gas emissions (CO_2) to the environment (according to statistical indicators of the State Statistics Service of Ukraine).

Mathematical and statistical processing of the conducted research results was conducted using the data analysis package programme *Microsoft Excel*.

RESULTS AND DISCUSSION

According to the data from the Ukrainian hydrometeorological centre, a detailed analysis of air temperature changes, precipitation, and relative humidity in Zhytomyr Polissia was conducted for 1961-2020. Lately, the region under study has seen an increase in the average annual air temperature by 3.0°C (Fig. 1).

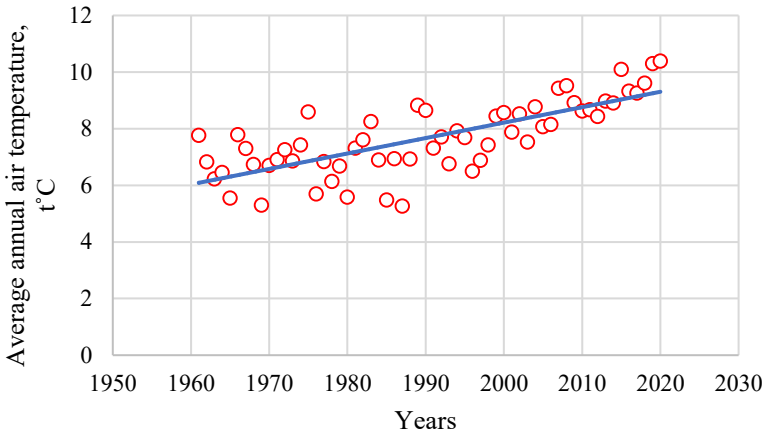

Figure 1. *Changes in the average annual air temperature in Zhytomyr Polissia for 1961-2020*

This warming directly affected the relative humidity of the air (Fig. 2), so over the past fifty-nine years, the relative humidity of the air has decreased by 3%.

There is also an increase in the average annual precipitation by 2 mm (Fig. 3).

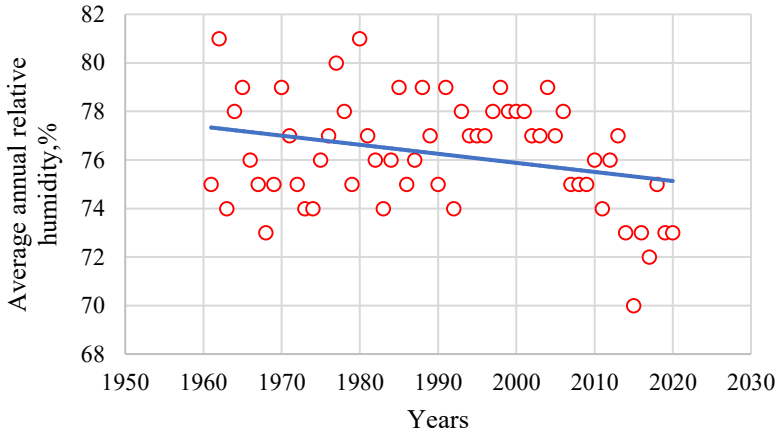

***Figure 2**. Average annual relative humidity in Zhytomyr Polissia for 1961-2020*

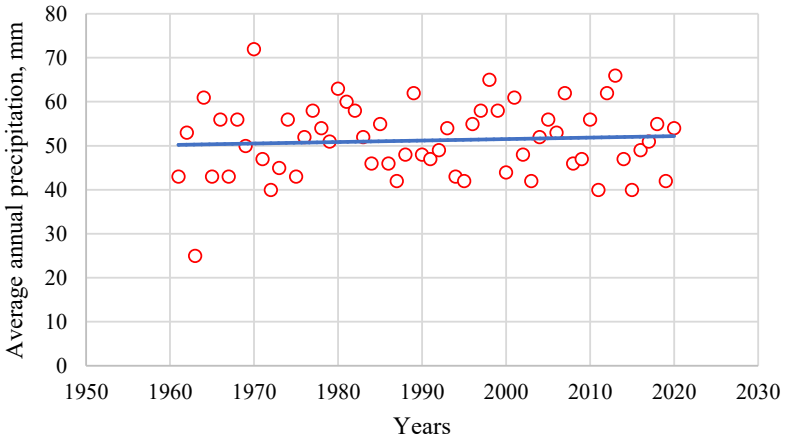

***Figure 3**. Average annual precipitation in Zhytomyr Polissia for 1961-2020*

Thus, the analysis of climate indicators demonstrated substantial climate changes in the region under study, such climate changes have an impact on biodiversity.

Since 2009, the State Agency for Forest Resources in Ukraine has carefully kept records of the occurrence of insect pest foci. According to the submitted reports of 2009-2020: Report on Forest Protection Works (Form No. 7 F), during research, the analysis revealed that the greatest harmful effect to pine woods in Zhytomyr Polissia is caused by:

– needle-eating pest – pine noctuid (*Panolis flammea* Denis & Schiffermuller), pine sawfly (*Diprion pini* L.), European pine sawfly (*Neodiprion sertifer* Geoffroy);

– other pest – pine bark bug (*Aradus cinnamomeus* Panz), pine lappet (*Dendrolimus pini* L.), pine looper (*Bupalus piniarius* L.) (Fig. 4).

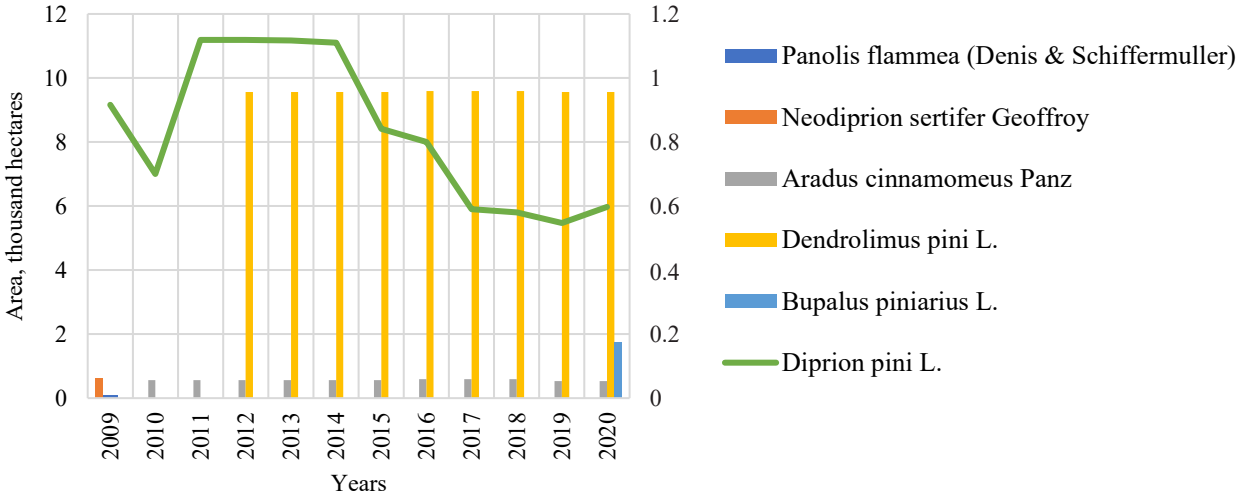

***Figure 4**. Dynamics of the emergence of insect pests in pineries for 2009-2020*

According to Figure 4, the greatest harmful effect is caused to pineries by a needle-eating pest – pine sawfly (*Diprion pini* L.) its largest foci were observed in 2011-2014 and amounted to 11.1 thousand hectares. Over the past four years, this number has decreased by almost 2 times. Pineries of Zhytomyr Polissia occupy 59% (Fig. 5) from other tree species, over 12 years, 20% of their area was damaged by insect pests.

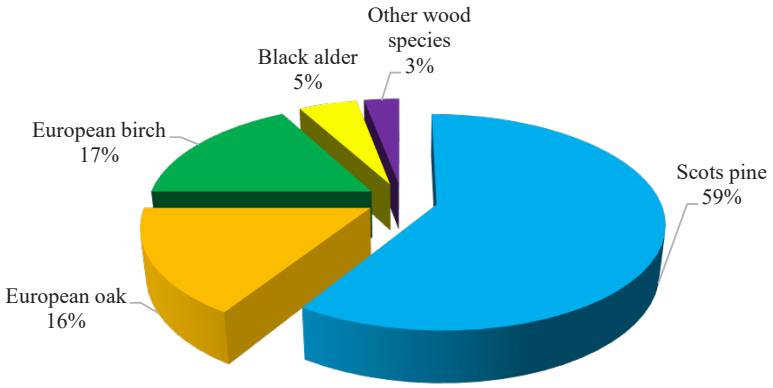

Figure 5. *Share of forest areas covered with forest vegetation by tree species in Zhytomyr Polissia*

Studying the dynamics of solar activity, the Wolf number (W number) for 2009-2020 indicated that the greatest solar activity was observed in 2011-2014; starting from 2015, there is a decrease in the W number (Fig. 6).

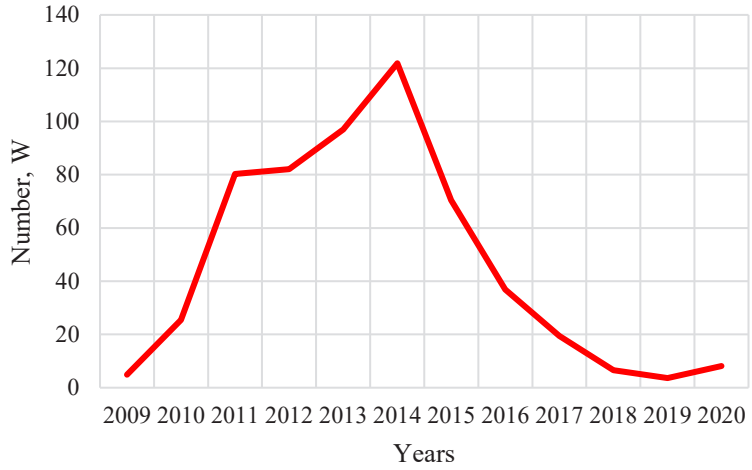

Figure 6. *Values of the average annual W numbers for 2010-2020*

Analysis of the dynamics of the W number (Fig. 6) and the area of trees damaged by insect pests (Fig. 4), reveals a certain pattern: during the solar activity increase in 2011-2014, the number of damaged pineries also increased, and in years of decreasing solar activity – vice versa. The same situation is observed upon analysing the impact of *Heterobasidion annosum* (Fr.) Bref. on pineries; since 2015, the area of plantings damaged by the root sponge has decreased with a decrease in solar activity (Fig. 7).

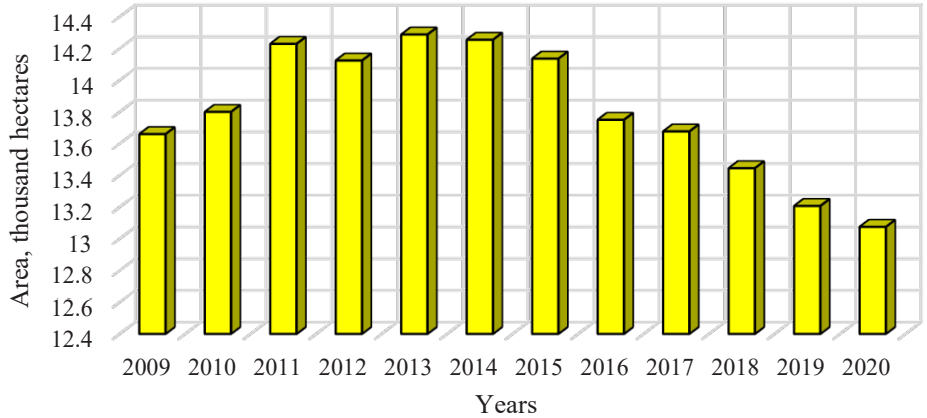

Figure 7. *Dynamics of Heterobasidion annosum occurrence for 2009-2020*

Applying the Eq. (1) by G.T. Selyaninov, the author of this study established the change in climate humidity in the conditions of Zhytomyr Polissia for 2009-2020 (Fig. 8).

According to the analysis results, 2015 was described by a year of average drought; 2009 and 2016 – years of mild drought; 2010-2012, 2018-2020 – years of adequate humidity; and 2013 – excessively humid year.

To find out if there is a correlation between the W number and CO_2 emissions, the study analysed the carbon dioxide emissions into the environment for 2009-2020 (Fig. 9).

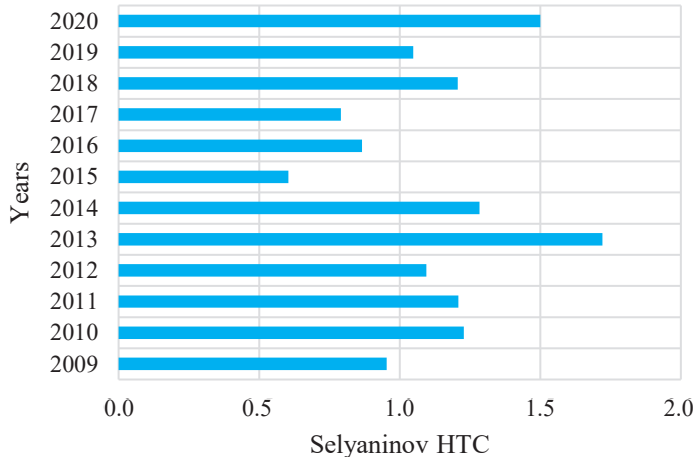

Figure 8. *G.T. Selyaninov Hydrothermal Coefficient Selyaninov*

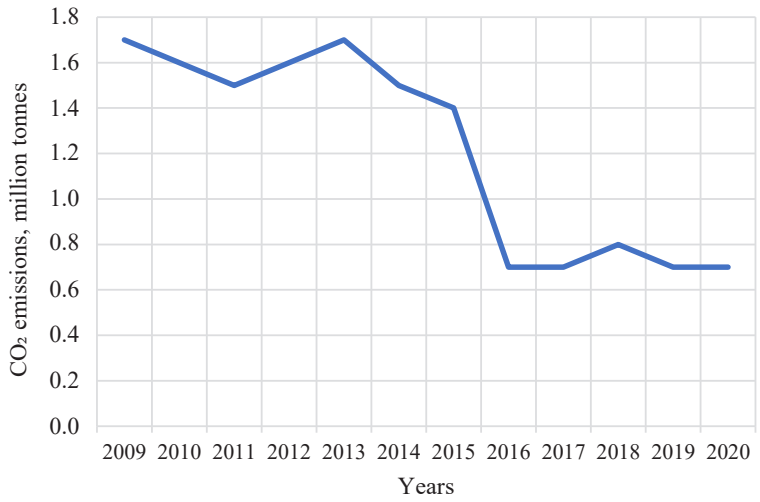

Figure 9. *CO_2 emissions in the natural environment for 2009-2020 (According to the Main Statistics Department of Zhytomyrska Oblast)*

According to the data presented in Figure 9, since 2014, the amount of CO_2 emissions has decreased almost three times. To establish correlations between the area of occurrence of insect pests and Heterobasidion annosum, CO_2 emissions, the W number, the Selyaninov HTC and the average annual air temperature, the average annual relative humidity, and the average annual precipitation sum, the author of this paper applied the data analysis package *Microsoft Excel* and constructed the correlation matrix (Table 1).

Table 1. *Correlation matrix of paired coefficients*

Indicators	Area of trees damaged by insect pests, thousand hectares	Area of trees damaged by Heterobasidion annosum, thousand hectares	W number	Average annual air temperature, °C	Average annual relative humidity, %	Average annual precipitation, mm	Selyaninov HTC coefficient Selyaninov	CO_2 emissions, million tonnes
Area of trees damaged by insect pests, thousand hectares	1.000							

Table 1, Continued

Indicators	Area of trees damaged by insect pests, thousand hectares	Area of trees damaged by Heterobasidion annosum, thousand hectares	W number	Average annual air temperature, °C	Average annual relative humidity, %	Average annual precipitation, mm	Selyaninov HTC coefficient Selyaninov	CO_2 emissions, million tonnes
Area of trees damaged by Heterobasidion annosum, thousand hectares	0.849	1.000						
W number	0.899	0.895	1.000					
Average annual air temperature, °C	-0.567	-0.539	-0.424	1.000				
Average annual relative humidity, %	0.220	0.131	0.005	-0.643	1.000			
Average annual precipitation, mm	0.200	0.092	0.113	-0.461	0.789	1.000		
Selyaninov HTC coefficient	0.292	0.026	0.238	-0.343	0.563	0.586	1.000	
CO_2 emissions, million tonnes	0.746	0.748	0.599	-0.642	0.354	0.193	0.216	1.000

The results of the analysis of indicators suggest that the correlation is quite high (0.899; 0.895) between the following indicators: area of trees damaged by insect pests, area of trees damaged by Heterobasidion annosum and Wolf number. There is also a sufficient correlation between CO_2 emissions in the environment and the area of pineries damaged by insect pests and Heterobasidion annosum (0.746, 0.748). High paired correlation coefficients between solar activity and the area of damaged pineries by biotic factors contributed to the construction of cross-plots (Figs. 10, 11).

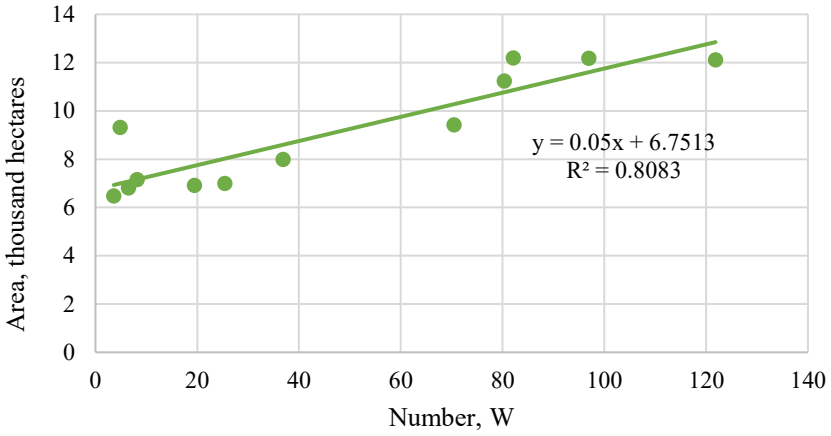

Figure 10. *Influence of the Wolf number on the area of woods damaged by insect pests*

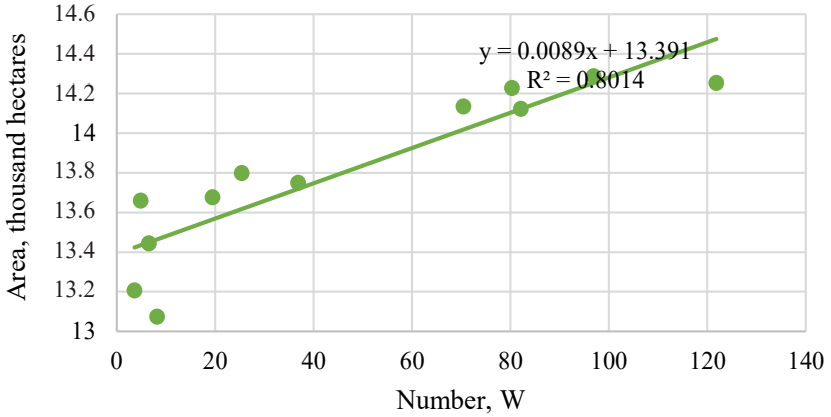

Figure 11. *Influence of the Wolf number on the area of woods damaged by Heterobasidion annosum*

The obtained mathematical dependences are 80% approximated with indicators and have a sufficiently high correlation coefficient, which allows applying empirical equations to predict the influence of the W number on damage to pineries by pests and forest diseases in the conditions of Zhytomyr Polissia.

CONCLUSIONS

In the conditions of Zhytomyr Polissia, climatic changes are observed, namely an increase in the average annual air temperature by 3.0°C, a decrease in the average annual relative humidity by 3%, and an increase in the average annual precipitation by 2 mm. It was found out that the greatest harmful effect of pine woods in Zhytomyr polissia is caused by pine noctuid (*Panolis flammea* Denis & Schiffermuller), pine sawfly (*Diprion pini* L.), European pine sawfly (*Neodiprion sertifer* Geoffroy), pine bark bug (*Aradus cinnamomeus* Panz), pine lappet (*Dendrolimus pini* L.), pine looper (*Bupalus piniarius* L.), and among phyto-diseases, *Heterobasidion annosum* (Fr.) Bref. causes significant harm.

A comprehensive analysis of various indicators for 2010-2020 confirmed the researchers' claims concerning the influence of the Wolf number and carbon dioxide emissions on the spread of insect pests and phyto-disease damage to pineries in Zhytomyr Polissia. It was established that the increase and decrease in solar activity directly affects the growth and decrease in the number of insect pests and phyto-diseases, respectively. The obtained mathematical dependencies can be of practical importance; they can be applied to predict outbreaks of insect pests and phyto-diseases to prevent their occurrence and predict measures to combat them.

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Сучасний стан соснових насаджень Житомирського Полісся за впливу екологічних чинників

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Анотація. В останні роки по цілому світі спостерігається масове всихання хвойних порід. У Північній Америці та Сибіру нараховується мільйони гектар всохлих насаджень, у Європі, за останні 20 років всихають сосни і ялини. Крім того, значних пошкоджень завдають деревним рослинам фітошкідники та фітохвороби, оскільки в Європі останніми роками спостерігається масове розмноження *Ips typographus* Linnaeus, *Ips acuminatus* Gyllenhal, у Північній Америці *Dendroctonus micans* Kud, в Східній Азії *Polygraphus proximus* Blandford. Також значної шкоди сосновим лісам завдають нематоди. Серед фітохвороб шкодочинну дію *Pinus sylvestris* L. завдає *Heterobasidion annosum* (Fr.) Bref. Виникнення осередків всохлих дерев у різних частинах земної кулі, вказує на глобальність процесів, що пов'язано з циклічними планетарними процесами та кліматичними змінами. У статті надано характеристику кліматичних змін у регіоні досліджень за період 1961–2020 рр. Відповідно до проведеного аналізу визначено, що за період 2009–2020 рр. значної шкоди сосновим насадженням Житомирського Полісся завдають серед хвоєгризучих – *Panolis flammea* Denis & Schiffermuller, *Diprion pini* L., *Neodiprion sertifer* Geoffroy; серед інших шкідників – *Aradus cinnamomeus* Panz, *Dendrolimus pini* L., *Bupalus piniarius* L. Найбільшу шкодочинну дію за останні роки завдає сосновим насадженням – *Diprion pini* L. Також з'ясовано, що серед фітохвороб сосновим лісам значної шкоди завдає *Heterobasidion annosum* (Fr.) Bref., пошкоджена площа становить від 13,0–14,2 тис. га. Проведено гідротермічний аналіз за період 2009–2020 рр. Проаналізовано вплив сонячної активності на чисельність фітошкідників та хвороб. Надано оцінку кількості викидів CO_2 у навколишнє природне середовище за період 2009–2020 рр. і з'ясовано що з 2014 р. кількість викидів діоксиду вуглецю зменшилася з 1,5 млн т на 0,6 млн т. Кореляційний аналіз всіх показників вказав на високий взаємовплив між площею пошкоджених дерев ентомошкідниками, кореневою губкою, числом Вольфа та викидами CO_2 в довкілля. Одержано математичні залежності з метою прогнозування впливу числа W на пошкодження соснових насаджень шкідниками та хворобами лісу в умовах Житомирського Полісся

Ключові слова: зміни клімату, фітошкідники та хвороби, викиди CO_2, сонячна активність, гідротермічний коефіцієнт, кореляція, математичне моделювання